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Staffing and Scheduling of Quality Assurance Inspections for Commercial Activities Contracts on Army Installations

by
John H. Williamson
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This report describes the procedures and results of a study done for the Directorate of Facilities Engineering, U.S. Army Support Command, Hawaii (DFE, USASCH), to determine appropriate staffing levels for inspection work to be done by Government personnel on a potential service contract under the Commercial Activities (A-76) program. An on-site analysis was made of the expected workload, proposed inspection strategies, and proposed inspection requirements as prepared by the DFE. Staffing requirements for the inspection work force were determined by considering inspector skill category and location, and duration and frequency of inspections. Because inspector productivity varies with geographic location, automated modelling techniques were used to optimize the inspectors' time and calculate the necessary number of inspectors. The analysis led to recommendations for modifications to certain inspection strategies.

The procedures and results of this study can be applied to the problem of staffing and scheduling inspections for Commercial Activities contracts at other locations.

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FOREWORD

This research was conducted for the Directorate of Facilities Engineering, U.S. Army Support Command, HI (DFE, USASCH), under Reimbursable Work Unit PE7, "QA Inspection Validation and Resource Allocation Model." The USASCH Point of Contact was Mr. Steven Troute, DFE. The Technical Monitor was Mr. R. Hohenberg, CEHSC-FM-S.

The work was performed by the Facilities Systems Division (FS), U.S. Army Construction Engineering Research Laboratory (USACERL). Dr. Michael J. O'Connor is Chief of USACERL-FS. The USACERL technical editor was William J. Wolfe, Information Management Office.

COL Everett R. Thomas is Commander and Director of USACERL, and Dr. L.R. Shaffer is Technical Director.

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STAFFING AND SCHEDULING OF QUALITY ASSURANCE INSPECTIONS FOR COMMERCIAL ACTIVITIES CONTRACTS ON ARMY INSTALLATIONS

1 INTRODUCTION

Background

Office of Management and Budget (OMB) Circular A-76 and Department of Army (DA) Circular 235-1 require the Army to evaluate whether an outside contractor could perform many of the various tasks of running a facility at less cost to the Government than that of the in-house workforce in its most efficient structure.

Once the Army has purchased contractor services, it must ensure that the quantity and quality of the services received meet specified Army contract requirements. The contractor is responsible for Quality Control (QC), and the QC Plan in the contract contains guidance for contractor personnel on scheduling, methods, and inspection for work in progress.

The Army conducts Quality Assurance (QA) Surveillance to evaluate and document the contractor's performance. The contracting agency prepares a QA Surveillance Plan (QASP) with the contract which discusses the purpose of QA, methods for monitoring contractor performance, and implementation.

A common problem with the QC/QA arrangement is that the Army's QA Surveillance can duplicate the contractor's QC Program unless the Surveillance technique is carefully designed to inspect only selected portions of the completed work. This technique, called sampling, can be carried out in several ways, according to the type of work evaluated. A carefully designed inspection strategy for a Commercial Activities (CA) contract can enable the Army to determine whether the product or service (1) meets contract specifications, (2) complies with applicable regulations, and (3) promotes the operation of Army facilities and equipment throughout their normal useful life.

At the time of this study, the Directorate of Facilities Engineering (DFE), U.S. Army Support Command, HI (USASCH), had already been engaged in an evaluation of its contracted QA services, to determine if the quantity and quality of those services were sufficient to meet contract requirements. A Performance Work Statement (PWS) and Quality Assurance Surveillance Plan (QASP) were nearly complete and all data necessary to predict the Operations and Maintenance (O&M) requirements had been collected. A review of workload, geographic dispersion of the numerous sites on the island of Oahu, HI, and type of contract (Cost Plus Award Fee) made it clear that the standard authorized staffing level of contract management personnel (QA inspectors) was inadequate for the proposed contract. Further analysis was required to determine appropriate staffing levels. Other reviewing agencies can use this analysis to evaluate DFE waiver requests for additional inspectors.

Objectives

The objectives of this study were to create an automated modelling technique that optimizes the use of inspectors' time, and to employ that technique to determine the appropriate staffing level for inspection work to be performed by government personnel on potential service contracts under the Commercial Activities (A-76) programs, at the U.S. Army Support Command at Oahu, HI.

Approach

Initial Analysis

In the initial stages of this study, USACERL reviewed the Performance Requirements Summary, projected contractable workload, initial inspection strategies, and inspector workload. In addition, the relationships between the geographic location of inspectors' base of operations, the location of isolated work sites, and the average travel time between these points, were analyzed. Network diagrams of the geographic and travel time relationships of the USASCH installations (Figure 1) were constructed and verified by DFE personnel. This network was used in the final phase of study to determine the number of inspectors needed to perform the required inspections. During this initial analysis, possible exceptions to commonly accepted inspection practices were identified and some preliminary recommendations were developed to be verified during the on-site stage of this study.

Detailed On-Site Analysis

USACERL researchers visited the DFE, USASCH, 5 to 14 October 1987, and with the support of DFE personnel reviewed the inspection requirements for the proposed contract. Details of this review appear in Chapter 2.

Estimated contractor workload, based on FY86 data, was separated into logical functional categories for analysis. Automated data analysis techniques were used to designate O&M activities by type and location of work performed, to determine frequency and duration of inspection for each category of inspector at each installation.

Determination of Inspector Staffing Requirements

The final stage of this study used the inspection requirement data from the on-site analysis and travel time information from the initial analysis to construct a computer model for the transportation/distribution of the Quality Assurance Estimates (QAEs) for the surveillance of the proposed contract. The computer model was developed during the on-site data analysis stage using estimated inspector workloads, which were updated as actual data became available.

The USASCH inspection methodology was changed substantially during the review period. An in-progress review showed that procedures which diverged from standard practice early in the study were later changed to use MIL-STD-105E, *Sampling Procedures and Tables for Inspection by Attributes* (10 May 1989),* as the basis for random sampling to better define the workload using contractor performance output as the basis for establishing the sampling population. These new approaches allowed an adequate sampling of the contractor's work without unnecessary duplication of the contractor's QC efforts.

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* At the time of this study, the current military standard for random sampling was MIL-STD-105D. This standard has been superceded by MIL-STD-105E (10 May 1989).

Western Group   Eastern Group
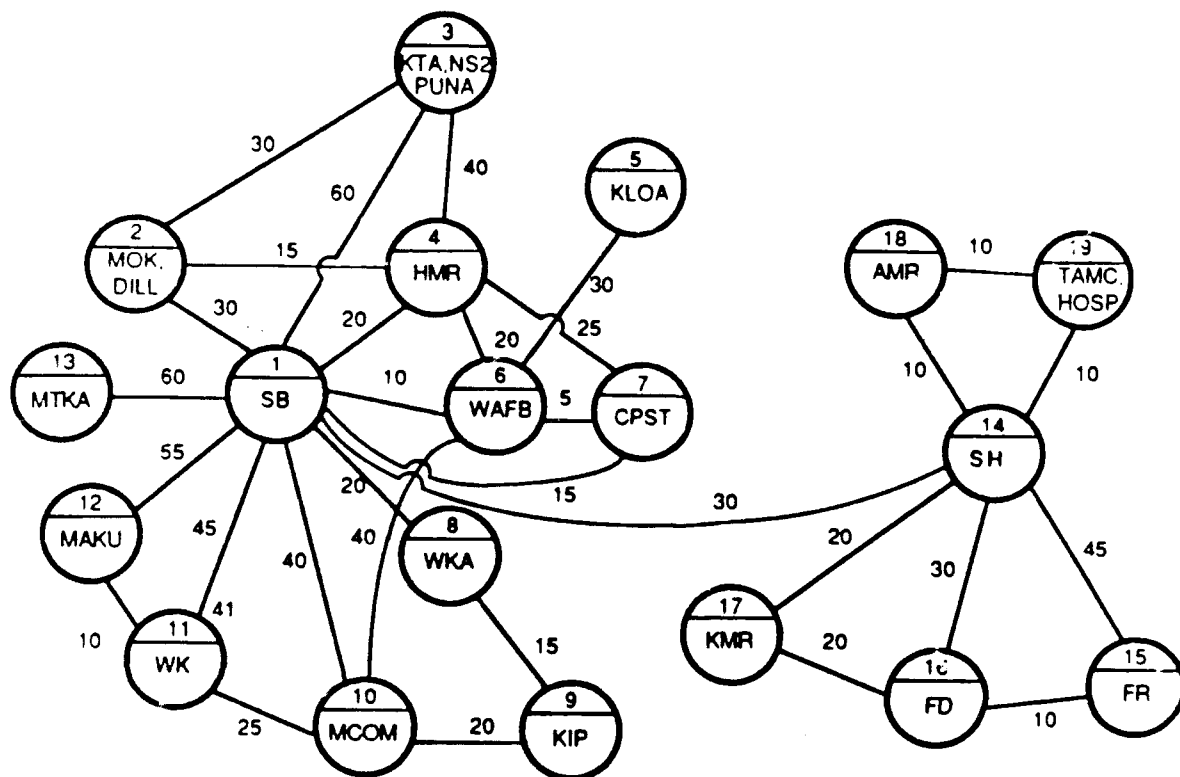
(Nodes represent locations. Arcs represent roads.
Travel times in minutes are shown for every arc.)

Figure 1. Network of Installation Sites and Travel Routes.

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2 INSPECTION WORKLOAD ANALYSIS

An analysis of the workload to predict and schedule inspection requirements requires that the work be separated into accounting classifications and inspector skill categories. Further separation of the workload into logical geographical locations and the development of a travel time network allows consideration for travel between locations when determining inspector staffing requirements.

The following example, based upon the study at DFE, USASCH, illustrates the procedure:

Work Classification

The DFE typically performs three types of contractable work:

1. Service Orders (SOs): small work requirements usually defined as not exceeding 80 hours of labor for maintenance and repair work, or 40 hours of labor for "new work"

2. Individual Job Orders (IJOs): separate, unique, one-time work orders, each of at least $2000 or at least 80 hours of labor

3 Standard Operating Orders (SOOs): cyclic, routine tasks done on a predetermined schedule.

The DFE, USASCH, had recorded the quantity, type, and location of work in each categories and entered it into a database management system to allow sorting by any desired analysis scheme.

Skill/Trade Categories

An inspector must be familiar with the type of work being performed to make a thorough inspection and to provide a meaningful analysis of the quality of contractor performance. This study focused on the skills as well as the number of inspectors needed. The following skill or trade categories (Table 1) demonstrate specialized areas of inspection for a large CA contract. Inspection staffing for a smaller contract may require combining some of these categories.

Table 1

Inspection Skill/Trade Categories

Carpentry	Interior electric
Plumbing	Sheet metal
Painting	Air conditioning
Paving	Grounds
Heating & boiler	Masonry
Exterior electric	Entomology
Water services	Sewage services
Miscellaneous	High security*
Locksmith	Complaint validation*
General construction**	

*Separate category due to special inspection requirements.

**One person who inspects several trades in complex IJO projects.

Geographic Locations

The geographic dispersion of locations at which work is performed significantly affects the number of inspectors required. Often the travel time to and from a remote site will exceed the time required for the actual inspection. The inspectors at DFE, USASCH, are based at two central locations, Fort Shafter and Schofield Barracks, but travel to other sites to make inspections and then return to base at the end of each work day. Workload was identified by location, which was referenced by code (Table 2).

Figure 1 illustrates the network of installations. Each node represents an installation numbered and identified by location code. An arc connects each pair of installations linked by a direct route. The number labeling each arc represents travel time, in minutes, between the two installations. The SCTS installation has negligible inspection needs and is not included in the diagram. The FSK and KPST locations are treated separately and do not appear in the diagram.

Table 2

Location Codes

Location Name	Location Code
Aliamanu MR	AMR
Fort DeRussy MR	FD
Kapalama MR	KMR
Fort Ruger MR	FR
Fort Shafter MR	SH
Tripler Army Medical Center	TAMC
Hospital	HOSP
Schofield Barracks	SB
Signal Cable Trunking System	SCTS
USA Field Station, Kunia	FSK
Wheeler Air Force Base	WAFB
USA Reserve Center, Wailuku, Maui	MAUI
Waianae-Kai MR	WK
Mokuleia Army Beach	MOK
Helemano MR	HMR
Dillingham MR	DILL
Makua MR	MAKU
Mauna Kapu Comm Station	MCOM
Pupukea-Paalaa-Uka Mil Road	PURD
Kawailoa Training Area	KLOA
Nike-Hawaii Site 2	NS2
Kipapa Ammo Storage Site	KIP
Waikakalaua Ammo Storage Site	WKA
Kahuku Training Area	KTA
Camp Stover	CPST
Mt. Kaala	MTKA
Punamanue	PUNA
Kaena Point Satellite Tracking Station	KPST

Service Order (SO) Inspection Requirement Analysis

Analysis of SO historical records indicates that USASCH will, each year, require the performance of 130,618 SO inspections over all skill/trade categories. Further sampling of these service orders on a daily basis using 252 working days per year and the single sampling plan for normal inspection in MIL-STD-105D yields the number of daily SO inspections (Table 3).

Applying inspection times (ranging from 0.25 to 0.4 hours per service order) and average travel time between jobsites within each installation, Table 4 displays the inspection time requirement for each skill category at each installation. Inspection times are very short in installations with a very small number of service orders. Combining these times with inspection time requirements for SOOs would present a more realistic picture of inspector workload.

Table 3

Inspection Requirement by Skill Trade

Skill/Trade	Yearly Requirement	Daily Requirement
Carpentry	27327	8
Interior Electric	15500	5
Plumbing	23655	8
Sheet Metal	11534	5
Painting	6819	5
Air Conditioning	12321	5
Paving	4065	5
Grounds	5508	3
Heating & Boiler	2360	2
Masonry	3147	2
Exterior Electric	3803	2
Entomology	2230	2
Water Services	1443	2
Sewage Services	1049	2
Miscellaneous	5652	3
High Security	4205	5
Complaint Validation	*	

*Inspection requirements for this category are discussed later in this chapter.

Table 4
Service Order Inspection Requirements (hr)

Skill/ Trade	AMR	AFD	KMR	MFR	TAMC	HOSP	SCTS	WAFSK	MAUI	WOKK	HMRR	DILRLU	MACKU	MCOM	PURD	KLOA	NOS2	KIPA	WIKA	KTA	CPST	MTKA	PUNA	KPST
Carpentry	•	0.4/wk	0.4/wk	•	0.7/day 0.2/day 0.3/day 2.6/day	•	0.5/wk 0.5/day	0.4/mo 0.4/mo 0.4/mo 0.4/yr 0.4/yr	•	•	•	•	•	0.8/yr	•	•	•	0.4/yr	0.4/mo 0.4/mo 0.8/yr	0.8/mo 0.4/mo
Interior electric	0.4/mo 0.4/wk	0.8/yr	•	0.4/day 0.4/wk 0.8/wk 1.6/day	•	0.4/wk 0.316	0.4/yr 0.4/mo 0.4/mo 0.4/yr 0.4/yr	•	•	•	•	•	0.4/mo	•	•	•	•	0.4/wk 0.4/wk 0.4/yr	0.4/wk 0.4/wk
Plumbing	0.6/mo 0.2/wk	0.4/wk 0.2/mo	0.7/wk 0.3/day 2.6/day	•	0.5/wk 0.5/day	0.3/wk 0.4/mo	•	•	0.4/mo	•	•	•	0.8/mo 0.4/mo	0.1/wk
Sheet metal	0.4/mo 0.4/mo	•	0.3/day 0.3/wk 0.6/wk 1.3/day	•	0.3/wk 0.3/day	0.4/mo 0.4/mo	•	•	0.2/mo	•	•	•	0.8/mo 0.4/mo	0.4/mo
Painting	0.3/yr 0.3/mo	•	0.3/day 0.3/wk 0.6/wk 1.3/day	•	0.3/wk 0.3/day	0.3/yr 0.3/mo	•	•	0.3/yr	•	•	•	0.3/mo 0.3/mo	0.3/mo
Air conditioning	0.4/yr 0.8/mo	0.4/mo 0.4/yr	0.4/wk 0.4/wk 0.8/wk 1.6/day	•	0.3/wk 0.3/day	0.8/yr 0.8/mo	•	•	0.4/yr	•	•	•	0.4/wk 0.4/mo	0.8/mo
Paving	0.3/yr 0.3/mo	•	0.2/day 0.5/mo 0.3/mo 0.7/day	•	0.6/mo 0.6/wk	0.3/yr 0.3/mo	•	•	•	•	•	•	0.3/mo 0.6/yr	0.3/mo
Grounds	0.3/yr 0.3/mo	•	1.0/wk 0.2/wk 0.3/wk 0.8/day	•	0.6/mo 0.8/wk	0.3/yr 0.3/mo	•	•	0.3/yr	•	•	•	0.6/mo 0.6/yr	0.3/mo
Heating & boiler systems	0.4/yr 0.4/mo	•	0.7/wk 0.6/mo 0.4/wk 0.7/day	•	0.4/mo 0.5/wk	0.4/yr 0.4/mo	•	0.4/yr	•	•	•	•	0.4/mo 0.8/yr	0.8/yr
Masonry	0.3/yr 0.3/mo	•	0.7/wk 0.4/mo 1.2/mo 0.5/day	•	0.4/mo 0.5/wk	0.3/yr	0.3/mo	•	•	•	•	•	0.3/mo 0.6/yr	0.3/mo
Exterior electric	•	•	0.6/wk 0.4/mo 0.8/mo 0.5/day	•	0.4/mo 0.5/wk	•	•	•	•	•	•	•	0.6/mo 0.3/mo	0.3/mo
Entomology	0.3/mo 0.9/yr	•	0.6/wk 0.5/mo 0.2/wk 0.5/day	•	0.3/mo 0.5/wk	•	•	•	0.6/yr	•	•	•	0.3/mo 0.3/yr	0.3/mo
Water services	0.4/mo 0.8/yr	•	0.8/wk 0.7/mo 0.3/wk 0.7/day	•	0.4/mo 0.8/mo	•	•	•	1.4/yr	•	•	•	0.4/mo 0.4/yr	0.8/yr
Sewage services	0.4/mo 0.8/yr	•	0.8/wk 0.5/mo 0.3/wk 0.7/day	•	0.5/mo 0.4/wk	•	•	•	0.4/yr	•	•	•	0.8/yr 0.4/yr	0.4/yr
Miscellaneous	0.4/mo 0.4/mo	•	1.0/mo 0.8/mo 0.4/wk 0.8/day	•	1.2/mo 0.8/wk	0.4/yr	0.4/mo	•	0.4/mo	•	•	•	0.4/mo 0.4/mo	0.4/mo
High security services					9.4/wk								4.6/wk	

*Number of SOs is negligible. The QA Supervisor may direct inspection, but not often enough to affect staffing levels.

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Any inspector may perform inspections in the "Miscellaneous" category, although an IJO inspector is preferable. An IJO inspector with security clearance should perform inspections in the "High Security" category.

IJO Inspection Requirement Analysis

Analysis of IJO historical records indicates that USASCH will require the performance of 223,880 hours of IJO inspection each year. These IJOs vary in size and in skill or trade involved. Since most IJOs are multitrade projects, the use of general construction type inspectors is recommended for this work, rather than sending multiple inspectors to a jobsite.

Table 5 lists the expected contractor IJO performance by labor hours and number of projects for each installation in USASCH. These quantities have decreased proportionally from past levels since the PWS has mandated a maximum of 69 labor-years of contractor IJO effort. Work requirements beyond the maximum are performed under other contractual arrangements, or not at all.

A few projects on remote sites, such as those on Maui and Johnston Island, required such infrequent inspections that they were not included in workload calculations. Full inspection at these sites is necessary only in the event of customer dissatisfaction. Otherwise, satisfactory performance can be confirmed by telephone with the requesting individual.

The number and frequency of inspections were based on the anticipated workload at each location, by size and number of jobs. For example, a small job of less than 2 days' duration requires only one inspection, but a large job lasting several days requires several inspections. An average inspection time of 1 hour, excluding travel time, was used in the analysis. Since in cost-plus contracting, the Government removes and replaces unsatisfactory work at its own expense, inspection should be frequent enough to minimize rework expense. The Government pays cost-plus contractors according to hours expended (not just on completion of a job), so inspection should be frequent enough to verify the hours a contractor has charged.

The USASCH methodology for establishing quality of contractor performance was appropriate and consistent with this analysis of IJO inspector requirements.

Standing Operations Order (SOO) Inspection Requirement Analysis

USASCH developed an automated database management system to calculate inspection requirements for SOO work. Using suggestions from various reviewing agencies, the well constructed approach ensures acceptable contractor performance without duplicating the contractor's QC efforts. The USASCH SOO inspection strategy embodies this philosophy.

Sampling Methodology

Locations and activities are usually selected for inspection by random sampling. At the direction of Western command (WESTCOM), MIL-STD-105D has been implemented to select sample sizes and to determine reject levels. The USASCH methodology, except for the critical task inspection discussed below, generally conforms to this accepted practice.

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Table 5

IJO Inspector Schedule

Loc Code	Job Hours	# Jobs	Avg Hr/Job	Crew Days/Job	# Insp/ Freq
AMR	699	15	47	1.5	1/mo
FD	1247	21	60	1.9	4/mo
KMR	1248	16	78	2.4	3/mo
FR	161	2	81	2.5	1/mo
SH	36129	477	76	2.4	4/day
TAMC	1768	44	40	1.3	4/mo
HOSP	7817	110	71	2.2	1/day
SB	46896	894	52	1.6	17/wk
SCTS	0	0	0	0	0
FSK	2995	15	200	6.3	4/mo
WAFB	12040	266	45	1.4	1/day
MAUI	*	*	*	*	1/yr
WK	613	11	56	1.7	1/mo
MOK	526	8	66	2.1	1/mo
HMR	3997	28	143	4.5	7/mo
DILL	*	*	*	*	1/yr
MAKU	37	3	12	0.4	1/qtr
MCOM	*	*	*	*	1/yr
PURD	*	*	*	*	1/yr
KLOA	*	*	*	*	1/yr
NS2	501	2	251	7.8	2/qtr
KIP	*	*	*	*	1/yr
WKA	*	*	*	*	1/yr
KTA	1481	3	494	15.4	2/mo
CPST	1594	5	319	10.0	2/mo
MTKA	189	6	32	1.0	2/qtr
PUNA	*	*	*	*	1/yr
KPST	398	14	28	0.9	1/mo

*No IJOs performed during FY86, but history indicates that one IJO per year is likely.

Critical Task Inspection

The USASCH has identified certain work so critical that it must be inspected more intensely than other work. Validating this USASCH requirement was beyond the scope of this study. However, MIL-STD-105D does provide for intensive inspection of critical work.

The DFE, USASCH, Performance Work Statement identifies five locations/activities as critical, as shown in Table 6.

The PWS reinforces the concept of criticality by defining the response time allowed for work performed at these locations. Field Station Kunia, the Kaena Point Satellite Tracking Station, and the Tripler Army Medical Center all require "Exceptional Emergency" response times. Both sewage and water plant operations require "Emergency" (Priority 1) response time.

Table 6

Critical Locations

Location	Rationale
Field Station Kunia (FSK)	Critical to national defense
Kaena Point Satellite Tracking Station (KPST)	Critical to national defense
Tripler Army Medical Center (TAMC)	Critical to life or health
Sanitary Sewage Plant	Critical to health; high penalty to Government in the event of noncompliance with effluent standards
Water Treatment Plant	Critical to health; removal of potentially dangerous groundwater contamination

Tables 7 to 17 illustrate SOO inspection requirements measured in hours.

Inspection in High Security Areas

In high security areas (Field Station Kunia and Kaena Point Satellite Tracking Station), an inspector with proper security clearance and the ability to inspect a wide range of activities is required. At USASCH these inspectors will usually also be IJO inspectors. Therefore, the work shown in Table 18 was added to the IJO inspection workload set forth on previous pages.

Customer Complaint Validation

Usually, one inspector assigned to this duty validates all customer complaints, which come mainly from occupants of family housing at a rate of 60 per week. For this analysis, the number of family housing units at six locations was used to determine proportionally the required inspector time at each location. Assuming a time of 1 hour for validation and follow-up of each complaint, Table 19 displays an inspector workload about equivalent to two full-time inspectors. This requirement applies to the entire inspection work force rather than to a particular inspector skill or category.

Administrative Tasks and Nonproductive Time

The inspector workload calculations presented in the preceding analysis include only the directly productive inspection work assignments for each inspector category at each of the USASCH installations. The time required for each inspector to perform indirectly productive tasks, such as filing reports and attending staff meetings, will reduce the amount of time available for inspection. Provisions should also be made for expected nonproductive time such as vacations and sick leave.

Table 7

SOO Inspection Hours
(Air Conditioning and Refrigeration)

Loc. Code	/Day	/Wk	/2Wk	/Mo	/Qtr	2/Yr	/Yr
AMR							
FD				4.2	0.6		1.9
KMR				2.8		1.5	6.5
FR					0.5		0.5
SH	1.0			17.1	2.1	1.0	0.6
TAMC		0.6		1.6	4.7	9.9	7.7
HOSP (intensive)				61.9			4.0
HOSP (normal)		1.5		31.9			4.0
SB		6.1		50.7	12.1	12.6	4.3
SCTS							
FSK (see high security)				15.7	8.5	9.0	7.4
WAFB							
MAUI							
WK							
MOK							
HMR				4.3	0.3	0.6	1.8
DILL							
MAKU							
MCOM							
PURD							
KLOA							
NS2							
KIP							
WKA							
KTA					1.2		1.0
CPST				5.1			
MTKA					0.6	1.3	0.3
PUNA							
KPST (see high security)							

Note: Blank entries indicate either no inspection requirements or negligible requirements.

Table 8

SOO Inspection Hours
(Exterior Electric)

Loc. Code	/Day	/Wk	/2Wk	/Mo	/Qtr	2/Yr	/Yr
AMR							
FD				3.6			0.2
KMR				1.5		0.5	4.5
FR							2.3
SH				12.4			
TAMC				4.5		1.2	0.7
HOSP (intensive)	0.4			41.2			8.0
HOSP (normal)	1.2			28.4			8.0
SB				18.7	0.2		6.0
SCTS							
FSK (see high security)							
WAFB				10.4	2.4	6.2	14.5
MAUI							
WK						1.2	8.5
MOK							
HMR				1.1			9.1
DILL							
MAKU				2.3			
MCOM				0.5			9.2
PURD							
KLOA							
NS2							
KIP				1.0		1.2	11.0
WKA				1.5			1.4
KTA					0.4	1.2	4.8
CPST				1.9			
MTKA		1.3		3.0			
PUNA				0.8			0.2
KPST (see high security)							

Note: Blank entries indicate either no inspection requirements or negligible requirements.

Table 9

SOO Inspection Hours
(Entomology)

Loc. Code	/Day	/Wk	/2Wk	/Mo	/Qtr	2/Yr	/Yr
AMR							
FD				9.2			
KMR				15.6			1.8
FR				1.1	1.1	1.2	
SH				38.9			
TAMC		0.8		13.2	2.2		
HOSP		29.0					
SB		3.4		58.4			
SCTS							
FSK (see high security)							
WAFB		2.7		13.3	3.3		
MAUI							
WK				2.7	0.4		3.3
MOK							
HMR		3.0		16.0			2.1
DILL							
MAKU				1.1			
MCOM							
PURD							
KLOA							
NS2				1.8			
KIP							
WKA				2.4			8.2
KTA					0.4		
CPST							
MTKA							
PUNA				0.7			
KPST (see high security)							

Note: Blank entries indicate either no inspection requirements or negligible requirements.

Table 10

SOO Inspection Hours
(Grounds)

Loc. Code	/Day	/Wk	/2Wk	/Mo	/Qtr	2/Yr	/Yr
AMR							
FD		3.2		12.2			
KMR							0.8
FR				0.5			
SH		22.0		34.4			
TAMC		9.7			0.7	1.3	
HOSP							
SB		28.7		18.2		7.5	8.0
SCTS							
FSK (see high security)							
WAFB		2.0		9.4			
MAUI							
WK							
MOK							
HMR		1.5		1.3		1.5	
DILL							
MAKU							
MCOM							
PURD							
KLOA							
NS2							
KIP							
WKA							
KTA					4.1		
CPST				4.8			
MTKA (intensive)		2.6		2.3			
MTKA (normal)		1.6		2.3			
PUNA							
KPST (see high security)							

Note: Blank entries indicate either no inspection requirements or negligible requirements.

Table 11

SOO Inspection Hours
(Heating)

Loc. Code	/Day	/Wk	/2Wk	/Mo	/Qtr	2/Yr	/Yr
AMR							
FD				0.3		0.3	0.9
KMR							
FR				1.0		0.1	0.3
SH				4.9			
TAMC				0.8		0.4	1.0
HOSP (intensive)		11.5		14.7		1.5	7.3
HOSP (normal)		8.0		4.7		1.5	7.3
SB (intensive)		10.2		17.7		3.6	13.4
SB (normal)		6.3		17.7		3.6	13.4
SCTS							
FSK (see high security)							
WABF		1.0		1.2		1.8	8.2
MAUI							
WK							
MOK							
HMR			3.9			0.3	0.5
DILL							
MAKU							
MCOM							
PURD							
KLOA							
NS2				0.3			
KIP							
WKA							
KTA							
CPST							
MTKA							
PUNA							
KPST (see high security)							

Note: Blank entries indicate either no inspection requirements or negligible requirements.

Table 12

SOO Inspection Hours
(Interior Electric)

Loc. Code	/Day	/Wk	/2Wk	/Mo	/Qtr	2/Yr	/Yr
AMR							
FD				1.0			
KMR							
FR							
SH				8.5			
TAMC				0.8	1.0		3.0
HOSP		3.6		16.2			5.6
SB				12.8			4.0
SCTS							
FSK (see high security)							
WAFB				10.0	3.0		3.5
MAUI							
WK							
MOK							
HMR				1.0		5.5	
DILL							0.5
MAKU				1.1			
MCOM							
PURD							
KLOA							
NS2							0.3
KIP							
WKA							
KTA							
CPST							0.5
MTKA							1.0
PUNA							2.5
KPST (see high security)							

Note: Blank entries indicate either no inspection requirements or negligible requirements.

Table 13

SOO Inspection Hours
(Organizational Maintenance)

Loc. Code	/Day	/Wk	/2Wk	/Mo	/Qtr	2/Yr	/Yr
AMR							
FD							
KMR							
FR							
SH				6.3			3.2
TAMC							
HOSP							
SB					8.7	11.4	13.4
SCTS							
FSK (see high security)							
WAFB							
MAUI							
WK							
MOK							
HMR							
DILL							
MAKU							
MCOM							
PURD							
KLOA							
NS2							
KIP							
WKA							
KTA							
CPST							
MTKA							
PUNA							
KPST (see high security)							

Note: Blank entries indicate either no inspection requirements or negligible requirements.

Table 14

SOO Inspection Hours
(Building Plumbing)

Loc. Code	/Day	/Wk	/2Wk	/Mo	/Qtr	2/Yr	/Yr
AMR							
FD				0.4			
KMR				12.8			1.0
FR				0.4			
SH				7.7		1.2	4.9
TAMC				4.0	1.2		6.4
HOSP				9.5			2.0
SB				8.7	6.0	0.9	4.8
SCTS							
FSK (see high security)							
WAFB				4.6	3.2	3.9	1.4
MAUI							
WK							2.1
MOK							
HMR				1.6		2.1	0.4
DILL							
MAKU							
MCOM							
PURD							
KLOA							
NS2							
KIP							
WKA							
KTA							
CPST							0.3
MTKA							
PUNA							
KPST (see high security)							

Note: Blank entries indicate either no inspection requirements or negligible requirements.

Table 15

SOO Inspection Hours
(Surfaced Areas)

Loc. Code	/Day	/Wk	/2Wk	/Mo	/Qtr	2/Yr	/Yr
AMR							
FD		1.0		2.6			
KMR				7.0			0.4
FR							
SH				9.0		0.5	
TAMC		1.0		18.8			
HOSP							
SB		0.3		6.1		0.2	4.8
SCTS							
FSK (see high security)							
WAFB		1.0		4.2		7.4	
MAUI							
WK						1.8	
MOK							
HMR				0.6			
DILL							
MAKU				0.1			
MCOM							
PURO							
KLOA							
NS2							
KIP							
WKA							
KTA							
CPST				0.1			
MTKA							
PUNA							
KPST (see high security)							

Note: Blank entries indicate either no inspection requirements or negligible requirements.

Table 16

SOO Inspection Hours
(Sewage Systems)

Loc. Code	/Day	/Wk	/2Wk	/Mo	/Qtr	2/Yr	/Yr
AMR							
FD							6.5
KMR							10.0
FR							1.0
SH		0.3		11.8	0.4	1.5	2.2
TAMC				1.3			12.0
HOSP							
SB (intensive)	1.0	12.2		13.5	4.9	8.6	6.3
SB (normal)			17.5	4.9	8.6	6.3	
SCTS							
FSK (see high security)							
WAFB (intensive)		6.5		7.8	0.8	0.9	0.9
WAFB (normal)		5.5		3.8	0.8	0.9	0.9
MAUI							
WK							
MOK							
HMR (intensive)		5.5		21.4	0.2	0.2	2.0
HMR (normal)			16.3	0.2	0.2	2.0	
DILL							
MAKU							
MCOM							
PURD							
KLOA							
NS2							
KIP							
WKA							
KTA				3.2			
CPST		1.6		2.0			0.3
MTKA							
PUNA							
KPST (see high security)							

Note: Blank entries indicate either no inspection requirements or negligible requirements.

Table 17

SOO Inspection Hours
(Water Systems)

Loc. Code	/Day	/Wk	/2Wk	/Mo	/Qtr	2/Yr	/Yr
AMR							
FD				0.6			
KMR				2.9			0.6
FR				0.4			
SH				8.0	0.6	0.1	
TAMC		2.3		1.9	1.2	1.2	
HOSP							
SB (intensive)	1.0	2.7		3.3	10.2	4.2	2.6
SB (normal)				5.9	10.2	4.2	2.6
SCTS							
FSK (see high security)							
WAFB (intensive)		0.9		1.3	6.2	0.8	0.6
WAFB (normal)				1.8	6.2	0.8	0.6
MAUI							
WK				0.5	0.7	0.3	0.3
MOK							0.4
HMR					0.3		0.9
DILL				0.3			
MAKU							
MCOM							
PURD							
KLOA							
NS2							
KIP							
WKA							
KTA					3.1	3.9	1.7
CPST				1.0			0.2
MTKA		0.5		3.1	0.8		2.6
PUNA				1.0			
KPST (see high security)							

Note: Blank entries indicate either no inspection requirements or negligible requirements.

Table 18

Multitrade (IJO) Inspector Hours

Loc. Code	/Day	/Wk	/2Wk	/Mo	/Qtr	2/Yr	/Yr
FSK (intensive)	0	42.9	0	82.0	4.2	11.3	65.6
FSK (normal)	0	28.9	0	82.0	4.2	11.3	65.6
KPST (intensive)	2.9	0	0	50.2	23.7	22.1	10.4
KPST (normal)	0.9	1.5	0	50.2	23.7	22.1	10.4

Table 19

Customer Complaint Validation

Loc. Code	Hsg Units	# Insp/ Freq
SH	669	8/wk.
TAMC	216	3/wk.
SB	3568	8/day
WAFB	492	6/wk.
HMR	32	18/yr.
CPST	200	9/mo.

3   DESCRIPTION OF RESOURCE ALLOCATION MODEL

As the foregoing analysis of the inspection requirements became available, researchers at the University of Illinois Department of Mechanical and Industrial Engineering developed an automated resource allocation model for determining inspection staffing requirements.[1]   This chapter describes the model and its development.

Problem Formulation

The Model

The following model represents a mathematical statement of the problem of finding the minimum number of inspectors needed to perform all QA tasks belonging to a particular skill category at widely dispersed locations where travel time is significant. Interaction among skill categories occurs only where multitrade inspectors, who are treated as a separate skill category, are needed. Therefore, the mathematical model and the solution procedure assume a single skill category. The model and procedure also assume that all inspectors are based at a single station.

Let:

i or j =	a site,	i, j = 1, ..., m,
k =	a skill category,	k = 1, ..., n,
w =	a working day,	w = 1, ..., W,
p =	a class of inspection frequency,	p = 1, ..., P.

Thus m is the number of sites, n the number of inspectors and W = 252 the number of working days per year. Table 20 shows inspection frequency and the frequency of class p inspection (f_p is the frequency or number of visits per year required to perform each class p inspection activity).

Table 20

Inspection Frequency by Class

Frequency Class (p)	Inspection Frequency	f_p (Visits per Yr)
1	Daily	252
2	Weekly	52
3	Biweekly	26
4	Monthly	12
5	Semiannually	2
6	Annually	1

[1]M. I. Dessouky et al., *Development of an Inspection Resource Allocation Model*, Operations Research Laboratory Report 87-007 (University of Illinois Department of Mechanical and Industrial Engineering, Urbana, IL, November 1987).

Given:

d_{ip} = duration of class p inspection demand at site i in minutes per visit

h_{ip} = the need for class p inspection at site i

$$H_{IP} = \begin{cases} i & \text{if } d_{ip} > 0 \\ 0 & \text{Otherwise} \end{cases}$$

a_{kw} = time available for inspector k on day w in minutes

t_{ij} = travel time between sites i and j in minutes.

Find the following decision variables:

- The incidence of a visit by inspector k to a site i on day w given by:

$$y_{ikw} = \begin{cases} 1 & \text{if inspector k visits site i on day w} \\ 0 & \text{otherwise} \end{cases}$$

- The sequence in which sites are visited represented by:

$$x_{ijkw} = \begin{cases} 1 & \text{if inspector k visits site j immediately after site i i on day w} \\ 0 & \text{otherwise} \end{cases}$$

- The assignment of a visit to inspector k on day w expressed by:

$$z_{kw} = \begin{cases} 1 & \text{if } \sum_{i=1}^{m} y_{ikw} \geq 1 \\ 0 & \text{Otherwise} \end{cases}$$

- If q_{ikw} = inspection load of inspector k at site i on day w in minutes, then find q_{ikw} and the need for an inspection visit to site i on day w expressed as:

$$b_{iw} = \begin{cases} 1 & \text{if } \sum_{k=1}^{n} q_{ikw} > 0 \\ 0 & \text{Otherwise} \end{cases}$$

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- The daily assignment of inspection tasks denoted by:

  S_{ikpw} = time in minutes spent at site i by inspector k to perform class p tasks in day w.

To minimize n, subject to:

$$\sum_{w=1}^{W} \sum_{k=1}^{m} S_{ikpw} = d_{ip} \, f_p \qquad \text{[Eq 1]}$$

where i = 1,...,m
           p = 1,...,P.

$$\sum_{p=1}^{P} S_{ikpw} - q_{ikw} = 0 \qquad \text{[Eq 2]}$$

where i = 1,...,m
           k = 1,...,n
           w = 1,...,W.

$$\sum_{w=1}^{W} \sum_{k=1}^{m} y_{ikw} \geq f_p h_{ip} \qquad \text{[Eq 3]}$$

for all i and p

$$S_{ikpw} \leq y_{ikw} M \qquad \text{[Eq 4a]}$$

for all i,k,p,w

$$S_{ikpw} \leq b_{iw} M \qquad \text{[Eq 4b]}$$

for all i,k,p,w

$$y_{ikw} \leq z_{kw} \qquad \text{[Eq 4c]}$$

for all i,k,w

where M is an arbitrarily large number.

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$$\sum_{w=1}^{W} z_{kw} \leq A \qquad\qquad\qquad \text{[Eq 5]}$$

for all k.

$$\sum_{k=1}^{n} y_{ikw} \geq b_{iw} \qquad\qquad\qquad \text{[Eq 6a]}$$

where   i   = 2, ...,m,
           w   = 1, ...,W.

$$\sum_{k=1}^{n} y_{ikw} \geq n \qquad\qquad\qquad \text{[Eq 6b]}$$

where   w   = 1,...,W.

$$\sum_{i=1}^{m} q_{ikw} + \sum_{i=1}^{m}\sum_{j=1}^{m} t_{ij} x_{ijkw} \leq a_{kw} \qquad\qquad\qquad \text{[Eq 7]}$$

where   k   = 1,...,m,
           w   = 1,...,W.

$$\sum_{j=1}^{m} x_{ijkw} = \sum_{j=1}^{m} x_{jikw} = y_{ikw} \qquad\qquad\qquad \text{[Eq 8]}$$

where   i   = 1,...,m,
          k   = 1,...,n,
          w   = 1,...,W.

$$\sum_{ij \in s} x_{ijkw} \leq \sum_{i \in S} b_{iw} \qquad\qquad\qquad \text{[Eq 9]}$$

for all S $\ni$ {2,...,m};
     k   = 1,...,n.

$$y_{ikw} \in \{0,1\},$$
$$x_{ikw} \in \{0,1\},$$
$$b_{iw} \in \{0,1\},$$
$$z_{kw} \in \{0,1\}$$

[Eq 10]

for all i,k,w

$$w_{ikpw} \geq 0$$
$$q_{ikpw} \geq 0$$

[Eq 11]

for all i,k,p,w

In the above mathematical formulation of the problem, constraints 1 to 5 are concerned with the assignment of daily inspection loads. Eq 1 implies that the total time spent by all inspectors at any site for class p inspection on day w is equal to the required inspection for that site and class of inspection. Eq 2 defines assigned workload for the inspector at a given site on a specific day. Since each class of inspection requires a certain number of visits every year, Eq 3 states that the number of visits to a site must be at least equal to that required for the most frequent class of inspection with positive demand. Eq 4a and 4b ensure that no inspection can be done at a site if it is not visited, while Eq 4c verifies that an inspector works on a day that he has to visit any site. Eq 5 restricts the number of working days for each inspector.

Eq 6a through 9 are routing constraints that ensure that visits to sites are made with minimal travel time, and that the time an inspector spends inspecting and traveling on any day does not exceed shift time. Eq 6a and 6b ensure that the inspectors visit each site a sufficient number of times. Eq 7 limits the time spent inspecting and traveling to the length of the shift. Eq 8 ensures that an inspector leaves a site after visiting it. Eq 9 eliminates subtours, thus guaranteeing connectivity and a return to the originating station.

Eq 10 contains integrality constraints while Eq 11 ensures nonnegativity of time variables.

Model Parameters

The most important parameters of the model are demand, time available for each inspector, and travel times (t_{ij}) between installations (sites). For this project, inspection demand was separated into three categories: SOO's, SO's, and IJO's. Jobs in high security areas were treated separately. Accordingly, the procedure determined the number of inspectors for three categories, the separate aggregates of SOO's and SO's, IJO's, and high security areas.

The time available for inspectors was based on an 8-hour working day. Allowing 60 minutes for administrative work and 30 minutes for breaks, an inspector is available for 390 minutes per day ($akw = 390$), for an average (A) 218 days a year.

Solution Methodology

Approach

The heuristic procedure segments the problem into load assignment and a subsequent routing problem. Inspectors are added sequentially; for each new inspector, first a load assignment is made and then a route is determined for each working day. These procedures are repeated until all inspection requirements are met for each skill category. Of the two basic procedures, the routing procedure has been implemented as a FORTRAN program on an IBM personal computer (PC).

The solution procedure for finding the minimum number of required inspectors (the problem stated in the preceding section) was based on the following assumptions and premises:

1.   A 1-year plan must be developed for each inspector of SOO and SO tasks that accounts for the cyclic nature of SOOs and the random nature of SOs.

2.   The plan must ensure that service is provided over 52 weeks or 252 days of the year, using inspectors available only 390 minutes per day, 218 days per year.

3.   The sites of all installations are partitioned into two groups: the western group, whose inspectors are stationed at Schofield Barracks, and the eastern group, whose inspectors are stationed at Fort Shafter. This grouping follows naturally from the geographic locations of the installations. Allocation of inspectors to routes is done separately for each group.

4.   The most frequent tasks at a site for a given skill category determine the minimum frequency of inspection visits to that site.

Based on these assumptions, the following guidelines were used to develop a computational procedure:

1.   Locations with most frequent demand (smallest p with nonzero demand) are considered first. That is, inspectors are first allocated to locations that should be visited daily, then to locations that should be visited weekly, and so forth.

2.   When an inspector is assigned to visit a location to perform a periodic (e.g., daily) inspection, less frequent (e.g., nondaily) inspection tasks are assigned during the same visit. This guideline maximizes the ratio between inspection and travel times and hence increases utilization of the inspector's time.

3.   An additional inspector is provided whenever one is needed to complete daily tasks, to perform nondaily tasks, or to substitute for absent inspectors.

4.   Separate computations are conducted for each skill category. Also, the number of inspectors is determined for three separate classes: skill-specific SOs and SOOs, multitrade IJO inspectors, and multitrade inspectors with security clearance for high security areas.

Procedure

The following procedure was used to determine the required number of inspectors for a particular skill and group of installations and consists of two phases: (1) data processing, and (2) determination of the number of inspectors.

Phase 1: Data Processing

Service Orders (SOs) and Standard Operating Orders (SOOs):

1. Construct the network representing installation location and travel time (t_{ij}) between them.

2. Categorize inspectors by skill, aggregating related skills.

3. Tabulate required inspection hours for each skill: For each of the 10 skills, each location i (i = 1 to 19), and each frequency class p (p = 1 to 6), add the required inspection hours of SOs and SOOs. To obtain the total yearly inspection load for each frequency class at each site, multiply the periodic requirement d_{ip} for each class p by the frequency of that class f_p.

IJOs and High Security Areas: Add the demand for IJO inspections, the SO and SOO requirements at high security areas (FSK and KPST), and the miscellaneous service requirements for all locations. These composite values will be used as demands for multitrade inspectors.

Phase 2: Determining the Number of Inspectors Required for Each Skill

1. Find the minimum number of inspectors required to satisfy the total demand at each location with daily demands. Construct shortest time tours if needed.

2. Compute the slack time for every inspector in terms of the number of hours available per day and the number of days for which this slack time is available.

3. Select the location with the most frequent nondaily demand from among all locations with unsatisfied demands. Attempt to meet the nondaily demand at this location using the slack time computed in (2) for available inspectors. If this is not possible, assign a new inspector to meet this demand. Update slack times. Construct shortest time tours if needed.

4. Repeat (3) until demand is satisfied at every location.

5. For each inspector, combine tours, if possible, to reduce an inspector's travel time.

Example: Determining Number of Building Inspectors

This example applies the steps of Phase 2 of the procedure to determine the minimum number of inspectors needed to perform building inspection tasks.

Consider locations with daily demand. There is a daily demand of 8.3 hr/day for 252 days at Schofield Barracks (SB), represented by node (1) in Figure 1, and 1.6 hr/day for 252 days at Wheeler Air

inspectors must visit every day. Since the number of productive days for an inspector covers only 218 of the 252 yearly workdays, at least one more inspector is needed. Figure 2 illustrates how the daily demand at SB is met by three inspectors (I, II, and III) with the current schedule:

Inspector I:

- Inspection time: 6.5 hr/day for 218 days

- Slack time: zero.

Inspector II:

- Inspection time: 1.8 hr/day for 184 days and 6.5 hr/day for 34 days

- Slack time: 4.7 hr/day for 184 days.

Inspector III:

- Inspection time: 1.8 hr/day for 68 days

- Slack time: 4.7 hr/day for 68 days and 6.5 hr/day for 150 days.
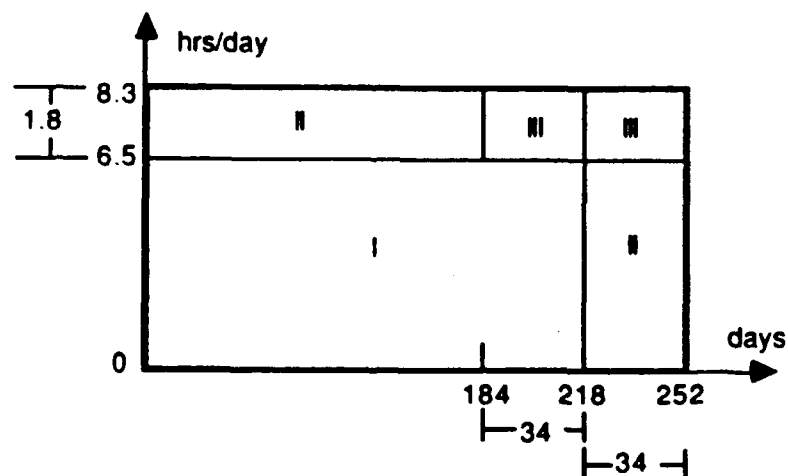
Figure 2. **Annual Manloading Profile of Inspectors I, II, and III for Daily Building Inspection at Schofield Barracks.**

Figure 3 shows current inspection loads for individual inspectors.

Since travel time between SB and WAFB is 10 minutes and the daily demand at WAFB is 1.6 hr/day for 252 days, the total time required is 1.93 hours/day for 252 days, assigned to Inspectors II and III:

Inspector II:

- Inspection time: 1.93 hr/day for 184 days

- Slack time: (4.7 - 1.93) = 2.77 hr/day for 184 days.

Inspector III:

- Inspection time: 1.93 hr/day for 68 days

- Slack time: (4.7 - 1.93) = 2.77 hr/day for 68 days and 6.5 hr/day for 150 days.

Updated load profiles for Inspectors II and III are shown in Figure 4.
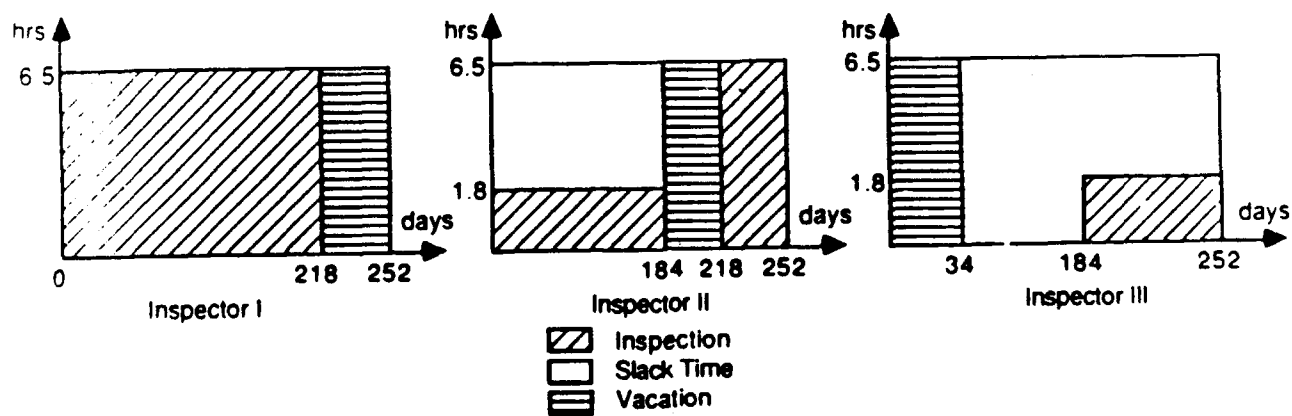
Figure 3. Current Individual Inspector Load Profiles for Daily Building Inspection at Schofield Barracks.

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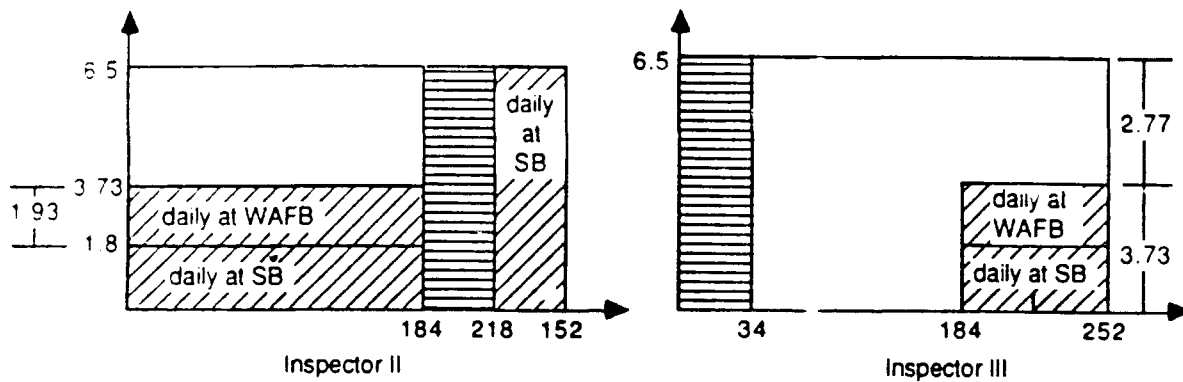
Figure 4. Load Profiles for Inspectors II and III for Daily Building Inspection at Schofield Barracks and Wheeler Air Force Base.

Next, slack time of Inspectors II and III is used to meet the nondaily demands at SB and WAFB, satisfying the most frequent demand first (e.g., weekly then monthly). The 184 days of slack time of Inspector II may be used to cover the following portion of the (252 day) year:

$$\frac{184 \times 52}{252} = 37.96 \approx 38 \text{ wks of the } 52/\text{yr,}$$

$$\text{or} \quad \frac{184 \times 12}{252} = 2.9 \approx 9 \text{ months of the } 12/\text{yr,}$$

$$\text{or} \quad \frac{184 \times 4}{252} = 2.9 \approx 3 \text{ quarters of the } 4/\text{yr,}$$

$$\text{or} \quad \frac{184 \times 2}{252} = 1.46 \approx 2 \text{ semiannual demands.}$$

Therefore, Inspector III should meet the remaining demand. That is, Inspector III must perform the weekly inspection for (38 - 15) = 14 weeks, the monthly for (12 - 9) = 3 months, and the quarterly for (4 - 3) = one quarter. The nondaily inspection demands at the daily visited nodes (SB and WAFB) are transformed to an equivalent number of inspectors' days in Table 21.

The number of equivalent inspection days required to satisfy the nondaily demand by Inspectors II and III are 65.73 and 20.24, respectively. Since 65.73 and 20.24 are less than the available equivalent slack days (184 and 68, respectively), these requirements can be met by using the slack times of Inspectors

II and III, meaning that a fourth inspector is not needed. The updated slack times for Inspectors II and III are:

$$\text{Slack time (II)} = 2.77 \text{ hr/day for } (184 - 66) = 118 \text{ days, and}$$
$$((1 - 0.73)(2.77)) = 0.74 \text{ hr for one day.}$$

$$\text{Slack time (III)} = 2.77 \text{ hr/day for } (68 - 21) = 47 \text{ days, and}$$
$$((1 - 0.24)(2.77)) = 2.1 \text{ hr for one day, and}$$
$$6.5 \text{ hr/day for } 150 \text{ days.}$$

Table 21

Equivalent Number of Days Required for Inspectors II and III To Perform Nondaily Inspection at Daily Visited Locations SB and WAFB

Freq.	#/yr	Demand (hr)	Location	Slack Time Equivalence (Inspector II)	Slack Time Equivalence (Inspector III)
Wkly	52	0	SB	$\dfrac{0.5 \times 38}{2.77} = 6.86$	$\dfrac{0.5 \times 14}{2.77} = 2.53$
		0.5	WAFB		
Mo	12	8.7	SB	$\dfrac{8.7 \times 9}{2.77} = 28.27$	$\dfrac{8.7 \times 3}{2.77} = 9.42$
		4.6	WAFB	$\dfrac{4.6 \times 9}{2.77} = 14.94$	$\dfrac{4.6 \times 3}{2.77} = 4.98$
Qtr	4	6	SB	$\dfrac{6 \times 3}{2.77} = 6.5$	$\dfrac{6 \times 1}{2.77} = 2.16$
		3.2	WAFB	$\dfrac{3.2 \times 3}{2.77} = 3.46$	$\dfrac{3.2 \times 1}{2.77} = 1.15$
2/yr	2	0.9	SB	$\dfrac{0.9 \times 2}{2.77} = 0.65$	
		3.9	WAFB	$\dfrac{3.9 \times 2}{2.77} = 2.82$	
1 yr	1	4.8	SB	$\dfrac{4.8}{2.77} = 1.73$	
		1.4	WAFB	$\dfrac{1.4}{2.77} = 0.5$	
		34 (Total)		65.73 days (Total)	20.24 days (Total)

Figure 5 illustrates these slack times.

Locations with weekly demands are HMR (node 4) and WK (node 11). This segment checks the feasibility of covering the requirements at these locations using the available slack times of Inspectors II and III. Table 22 shows the calculations for the number of hours required for nondaily inspections at these locations.

Table 22 determines the number of equivalent days required from Inspector II:

$$\text{available days (II)} = \frac{172.88}{2.77} = 62.41 < 118.$$

The equivalent number of days for Inspector III is:

$$\text{available days (III)} = \frac{60.44}{2.77} = 21.67 < 47$$

Thus, it is feasible to assign all inspections at weekly visited locations to Inspectors II and III. The updated slack times for Inspectors II and III are:

slack time (II) = 2.77 hr/day for (118-63) = 55 days
slack time (III) = 2.77 hr/day for (47-22) = 25 days, and
6.5 hr/day for 150 days.

Unvisited locations with monthly demands are shown in Table 23. Figure 6 shows the subnetwork of adjacent nodes that require daily, weekly, and monthly building inspections. The travel times between the nod ; are marked on the links. Inspectors' routes can be created by comparing the travel times occupied by individual and combined trips with available slack time.
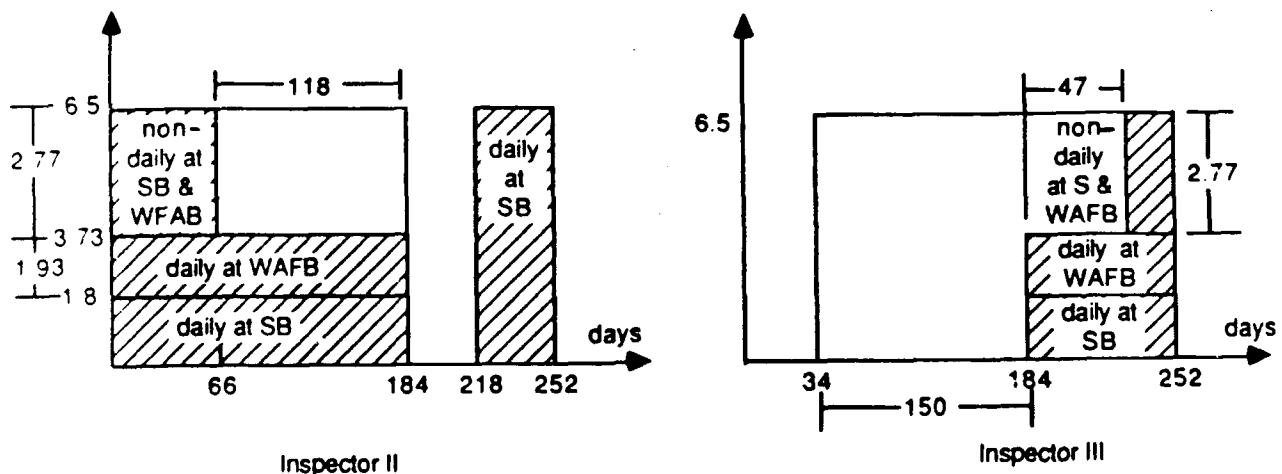

Figure 5. Load Profiles for Inspectors II and III for Total Building Inspection Requirements.

Table 22

Number of Hours Required for Weekly Visited Locations

		Demand (hr)			Inspector II		Inspector III	
	Insp. #/yr	Time	Travel Time	Location				
Wk	52	0.8	0.66	HMR	38(0.8+0.66)	= 55.48	14(0.8+0.66)	= 29.44
		0.6	1.5	WK	38(0.6+1.5)	= 79.8	14(0.6+1.5)	= 29.4
Mo.	12	2.6		HMR	9(2.6)	= 23.4	3(2.6)	= 7.8
		0.8		WK	9(0.8)	= 7.2	3(0.8)	= 2.4
2/yr	2	2.1		HMR	2(2.1)	= 4.2		
		0		WK				
1 yr	1	0.4		HMR	0.4	= 0.4		
		2.4		WK	2.4	= 2.4		
					172.88 (Total)		60.04 (Total)	

Table 23

Locations With Monthly Demands

Node	Location	/mo	/yr	Travel Time
(2)	DIL/MOK	1.2	0.7	1
(3)	PUNA	0.6	2.3	2
(7)	CPST	2.6	0.3	0.5
(13)	MTKA	1.5	0.6	2

A route which includes node (7) is generated by considering the following information:

Inspector II visits (4) 38 times with slack time = 2.77 hr per visit. The travel time of the tour (1,4,7,1) = T(1,4,7,1) = 20 + 25 + 15 = 60 min = 1 hr is less than T(1,4,1) + T(1,7,1) = (20+20) + (15+15) = 70 min = 1.16 hr. Therefore, Inspector II is routed to visit (7) from (4). Additional travel time = T(1,4,7,1) - T(1,4,1) = 60 - 40 = 20 min = 0.33 hr, and the available slack time (II) = 2.77 - 0.33 = 2.44 hr. Thus, Inspector II visits node (7) (2.6 × 9/2.44 = 9.59) ≈ 10 times, once per month for 8 months and twice on the ninth month to satisfy the monthly demand for 9 months and the yearly demand. Slack time for Inspector II is recalculated as:

Updated slack time (II) = 2.77 hr/day for (55 - 10) = 45 days

Inspector III should do the same route (2.6 × 3/2.44) ≈ 4 times to cover the demand for the remaining 3 months. The slack time for Inspector III is recalculated as:

Updated slack time (III) - 2.77 hr/day for (25 - 4)
                         - 21 days and 6.5 hr/day for 150 days.

A route which includes node (2) is generated by considering the following information:

Inspector II visits node (4) 28 times with slack time = 2.77 hr each time. To schedule Inspector II to visit node (2), the additional traveling time = 15 + 30 - 20 = 25 min = 0.42 hr, with remaining slack time = 2.77 - 0.42 = 2.35 hr. Thus, Inspector II visits node (2) nine times, eight of which are to meet monthly demand, with slack time 2.35 - 1.2 = 1.15 hr/day, and the ninth to meet monthly and yearly demand with slack time = 2.35 - 1.2 - 0.7 = 0.45 hr/day. Slack time for Inspector II is recalculated as:

Updated slack time (II) - 2.77 hr/day for (45 - 9)
                        - 36 days and 1.15 hr/day for 8 days and
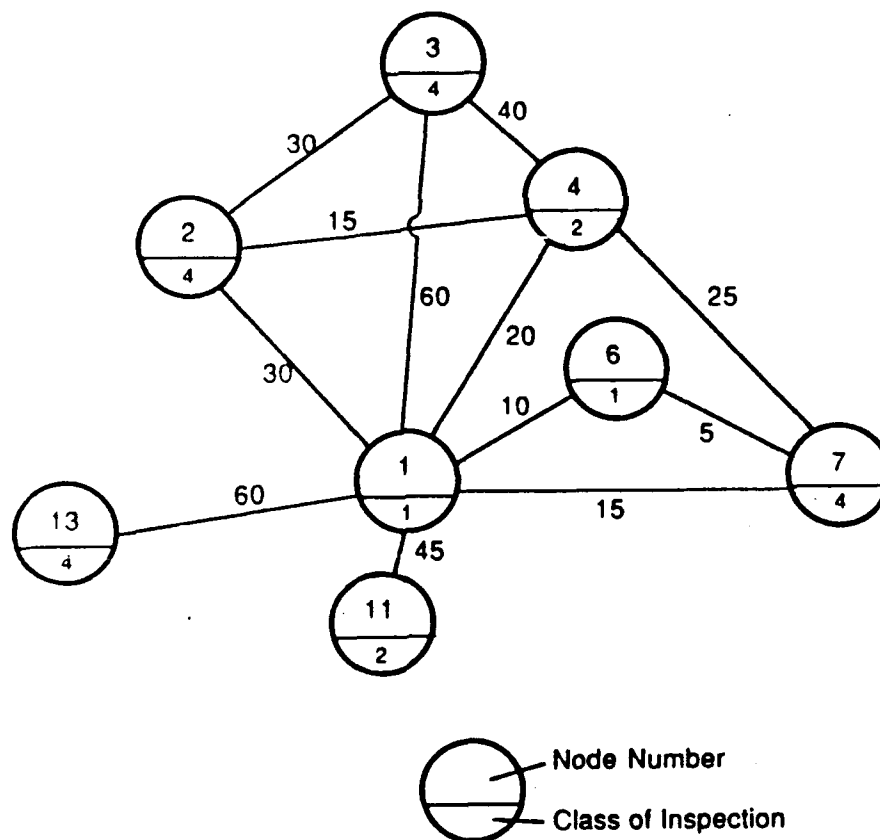   0.45 hr for 1 day.

Figure 6. Subnetwork of Locations Requiring Daily (1), Weekly (2), or Monthly (4) Building Inspection.

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Inspector III visits node (2) three times to cover the remaining monthly demand. Slack time for Inspector III is recalculated as:

Updated slack time (III) ▪ 2.77 hr/day for (21 - 3) ▪ 18 days and
1.15 hr/day for 3 days and
6.5 hr/day for 150 days.

A route which includes nodes (3) and (13) is generated using the following information:

Inspector II should visit node (3) ((0.6 × 9 + 2.3)/0.77) ≈ 10 times from node (1) to meet the monthly demand for nine months and the yearly demand (2.3 hr). Also, Inspector II can visit node (13) ((1.5 × 9 + 0.6/0.77) = 18.3)) ≈ 19 times from (1) to meet the monthly demand for 9 months and the yearly demand (0.6 hr). Slack time for Inspector II is recalculated as:

Updated slack time (II) ▪ 2.77 hr/day for (36 - 10 - 19)
▪ 7 days, and 1.15 hr/day for 8 days,
0.45 hr for 1 day,
and 0.54 hr for 1 day.

Inspector III should meet the monthly demand at (3) and (13) for the remaining three months:

$$\text{Node (3)} : \frac{0.6 \times 3}{0.77} = 2.33 \approx 3 \text{ visits}$$

$$\text{Node (13)}: \frac{1.5 \times 3}{0.77} = 5.84 \approx 6 \text{ visits}$$

Slack time for Inspector III is recalculated as:

Updated slack time (III) ▪ 2.77 hr/day for (18 - 3 - 6) ▪ 9 days and
1.15 hr/day for 3 days and
0.516 hr/day for 3 days and
0.123 hr/day for 6 days and
6.5 hr/day for 150 days.

The only unvisited location with yearly demand is MAKU (12) with 0.4 hr/yr demand. Figure 7 shows the tour (1,11,12,1) and the travel times for each link in this tour. Inspector II visits (11) 38 times/yr. Routing Inspector II to (12) from (11) incurs additional travel time [T(1,11,12,1) - T(1,11,1)] = (45 + 10 + 55) - (45 + 45) = 20 min = 0.33 hr. Therefore, Inspector II, on one of the 8 days with slack time of 1.15 hr, visits node (12) from (11) to meet its yearly demand. Recalculate slack time for Inspector II as:

Updated slack time (III) ▪ 2.77 hr/day for 7 days,
1.15 hr/day for 7 days,
0.54 hr for 1 day,
0.45 hr for 1 day, and
0.42 hr for 1 day.

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Further computation shows that the demand at SH (node 14) and its surrounding facilities requires a fourth inspector. The approach followed is to compute the total (travel + inspection) time required per year and to show that it is greater than the slack time availability of Inspector III but less than the available working hours of Inspectors III and IV combined. The slack time available for Inspector III (given previously) is equivalent to: $(2.77 \times 18 + 1.15 \times 3 \cdot \cdot 5.5 \times 150) = 1028.31$ hr/year. Total demand (TD) at every facility is computed as:

$$\text{TD} - 2 \times \text{travel time from SH to the facility}$$
$$+ \text{(sum of all periods)} \times \text{(demand/period)}$$
$$\times \text{(number of periods/year)}.$$

Applying the above formula to the input data of yearly inspection load for each frequency class at each site generates a total demand of 1,635.26 hr/year:

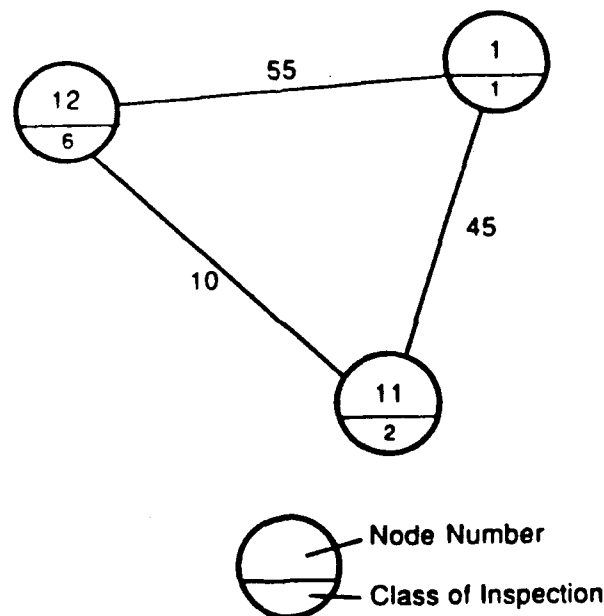|			
SH:	$2 \times 252 + 0.7 \times 52 + 7.7 \times 12 + 1.2 \times 2 + 4.9$	=	640.10 hr
FR:	$1.5 \times 12 + 0.6 \times 12$	=	25.20 hr
FD:	$1 \times 52 + 0.6 \times 52 + 1.4 \times 12$	=	100.00 hr
KMR:	$0.67 \times 52 + 0.8 \times 52 + 13.8 \times 12 + 1$	=	243.04 hr
AMR:	$0.33 \times 12 + 1 \times 12 + 0.6$	=	16.56 hr
TAMC:	$0.33 \times 252 + 0.8 \times 252 + 2.5 \times 52 + 15.2 \times 12 \times 4 + 8.4$	=	610.36 hr
TOTAL			1635.26 hr

Figure 7. Subnetwork of Tour Required by Inspector II for Yearly Inspection at Node 12.

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Total demand exceeds the available time of Inspector III; therefore, a fourth inspector (Inspector IV) is needed. Inspector III will be based at SB for 68 days and will spend the remaining 150 days at SH. Inspector IV will always be based at SH (218 days). Available time for Inspectors III and IV at SH is:

$$(6.5 \times 150) \text{ for Inspector III} + (6.5 \times 218) \text{ for Inspector IV} = 2392 \text{ hr/year.}$$

Slack time for Inspectors III and IV at SH is computed as:

$$2392 - 1635.26 = 756.74 \text{ hr/year.}$$

Results and Analysis

The previous discussion explains the computation of the number of inspectors needed for each skill group. Separate computations were carried out for intensive and normal levels of inspection. Table 24 summarizes the results obtained. Because of the small demand for inspection in organizational maintenance, no inspector is assigned to that category. This inspection will be covered by multitrade inspectors.

Analysis shows that intensive inspection would require one extra inspector with security clearance to handle the IJOs and high security areas. However, there is no effect on the number of inspectors required for the SOO and SO inspections because of the large amount of available slack time after satisfying normal inspection requirements.

Aggregating some types of inspection into a common skill category results in a smaller number of inspectors. Since inspection is done for 252 days and inspectors are each available for 218 days, at least two inspectors for each skill group are needed to cover all working days. Accordingly, if a skill group (such as building inspection) is split into its constituent skill categories (five for this group), the minimum number of inspectors required will be 10 rather than four. This implies that the inspectors will be extremely underutilized if skills are finely separated.

The number of inspectors required would be further reduced if multitrade inspectors were used to cover for inspectors on vacation. The economic feasibility of this substitution depends on the cost difference between multitrade and single trade inspectors.

Importantly, the number of inspectors presented in Table 24 exactly matches the calculated minimum number of required inspectors (Appendix). For this case, the results obtained on the basis of the data provided and the assumptions made are independently confirmed as optimal.

Table 24

Summary of Results

Skill Category		No. of Inspectors 252 Productive Days	No. of Inspectors 218 Productive Days
Building		4	4
Electric		3	3
Entomology		3	4
Grounds		4	4
A/C and refrigeration	(normal)	3	3
	(intensive)	3	3
Heating and boilers	(normal)	2	2
	(intensive)	2	2
Sewage		2	3
Surface		1	2
Water		1	2
Organization		0	0
Multitrade with security clearance (normal)		4	5
Multitrade with security clearance (intensive)		5	6
Multitrade without security clearance (normal)		1	1
Multitrade without security clearance (intensive)		1	1
Customer complaints		2	2
Total no. of inspectors	(252 productive days - normal)	= 30	
	(252 productive days - intensive)	= 31	
Total no. of inspectors	(218 productive days - normal)		= 35
	(218 productive days - intensive)		= 36

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4   CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The analysis described in this report and the output from the automated resource allocation model developed for this study (Chapter 3) have provided the basis for determining appropriate staffing levels for QA inspectors at USASCH. It is the conclusion of this study that the QA surveillance for each construction activity of the proposed CA contract at USASCH will require the following number of full-time Quality Assurance Evaluators.

1. Building Trades (carpentry, masonry, painting, sheet metal, and interior plumbing) (5)
2. Electric (3)
3. Multitrade (for IJO and High Security areas) (5)
4. Air Conditioning (4)
5. Paving (1)
6. Grounds (4)
7. Heating & Boiler (2)
8. Entomology (3)
9. Water Services (2)
10. Sewage Services (3)
11. Complaint Validation (2).

This study has not attempted to confirm the USASCH identification of facilities and activities as critical and therefore requiring more intensive inspection. Intensive surveillance, although not necessarily ensuring higher quality contractor performance, would detect defective performance almost immediately. Prompt action could then be taken to correct deviations from contract requirements. Assuming that the five areas which USASCH identified as critical require intensive inspection, this study also concludes that USASCH requires one additional full-time Quality Assurance Evaluator of the Multi-Trade skill category (for high security areas).

Recommendations

It is recommended that the methodology used in this study for calculating the staffing for the inspection portion of the residual work force be used by any installation during the cost comparison stage of a CA study. The results of this methodology can be used to support a request for approval of staffing level waivers by providing a realistic prediction of staffing requirements and by allowing for adequate surveillance of a contractor's work in the event of a CA contract award.

Since this study considered inspection strategies generally accepted throughout the Army, the nature of cost-plus contracting, and a geographic dispersion of many facilities, it is also recommended that this technique be applied to other installations that operate under CA contracts.

APPENDIX: Computation of Minimum Number of Inspectors

A minimum number of inspectors for every skill can be calculated by the following procedure:

(1)   Compute the total demand (TD) for every skill in terms of hr per year as follows:

$$TD = \text{(No. of hr/day} \times 252) + \text{(No. of hr/wk} \times 52)$$
$$+ \text{(No. of hr/mo} \times 12) + \text{(No. of hr/qtr} \times 4)$$
$$+ \text{(No. of hr/6 mo} \times 2) + \text{(No. of hr/yr)}.$$

(2)   Assume that each inspector works for 218 days every year and there are 8 working hr/day, 1 for administrative duties, 0.5 hr for breaks, and 6.5 hr for inspection. Thus, the number of inspection hours available per inspector per year are:

$$6.5 \times 218 = 1417 \text{ hr per year.}$$

(3)   Define [X] to be the smallest integer that is greater than or equal to the real number x (for example, [2.1] = 3 and [1.9] = 2).

(4)   The minimum number of inspectors (NI) needed to meet the total demand per year (TD) of any skill is given by [TD/1417] = NI. That is, it is impossible to inspect for TD hours per year using less than NI inspectors.

(5)   If we use only NI inspectors, then the sum of the time available for travel time (TT) and the slack time (ST) for all NI inspectors is given by (1417 × NI - TD), which is equal to (NI - TD/1417)-(1417).

The values for (TD), (NI), and (TT + ST) for every skill are summed in Table A1.

Table A1

Inspector Workload by Skill

Skill	TD (hr/yr)	NI	TT (hr/yr)
Buildings	4372	4	1303.64
Electric	3571	3	680
Entomology	4369.8	4	1303.64
Grounds	5125.6	4	542.4
A/C (intensive)	3469.8	3	781.2
A/C (normal)	3187.8	3	1063.2
Water	1557.5	2	1276.5
Surface	1110.1	1	306.9
Sewage	3486.8	3	764.2
Heat and boilers (normal)	1603.8	2	1230.2
Heat and boilers (intensive)	2108.6	2	725.4
IJO (intensive)	8273.6	6	228.4
IJO (normal)	7041.6	5	43.4

ABBREVIATIONS

CA	Commercial Activities
DA	Department of the Army
DFE	Directorate of Facilities Engineering
IJO	Individual Job Order
O&M	Operations and Maintenance
OMB	Office of Management and Budget
PWS	Performance Work Statement
QA	Quality Assurance
QAE	Quality Assurance Evaluator
QASP	Quality Assurance Surveillance Plan
QC	Quality Control
SO	Service Order
SOO	Standard Operating Order
USASCH	U.S. Army Support Command, Hawaii
WESTCOM	Western Command

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